EVALUATION OF COMPOST SPECIFICATIONS

FOR STORMWATER MANAGEMENT

A Thesis

by

LINDSAY NICOLE BIRT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2007

Major Subject: Biological and Agricultural Engineering

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Approved by:

Co-Chairs of Committee,	Patricia Smith
	Russell Persyn
Committee Members,	Bani Mallick
Head of Department	Gary Riskowski

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ABSTRACT

Evaluation of Compost Specifications for Stormwater Management.

(May 2007)

Lindsay Nicole Birt, B.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. Patricia Smith
Dr. Russell Persyn

Urban development will continue to increase in Texas because of population growth and urban sprawl. Despite the desire for urbanization and expansion of the economy, this growth increases the amount of construction, which, if not properly managed, can increase non-point source pollution and threaten surface water quality. Therefore, Texas Department of Transportation (TxDOT) has approved and promoted the use of compost as a stormwater best management practice (BMP) during highway construction. The objectives of this study were to construct and calibrate an indoor rainfall simulator and to determine the effectiveness of using compost rather than conventional hydroseeding or topsoil to reduce erosion from disturbed soils. Runoff rates, interrill erosion, and interrill erodibility were determined and compared across five compost treatments following TxDOT specifications for compost applied as an erosion control and two control treatments of topsoil (TS) and hydroseeding (HS) applied at 5 cm depth. The simulator produced 89% uniformity using ten Veejet 80100 nozzles at a target rate of 100 mm h^{-1}. The surface runoff was collected after 5 minutes of rainfall (first flush) and during the last 30 minutes of rainfall (steady-state). The first flush mean runoff for GUC-5 treatment was significantly higher than all other treatments. All other treatments; 50% woodchips and 50% compost blend (ECC-1.3, ECC-5), and hydroseeding (HS) had significantly lower runoff and erosion rates compared to topsoil (TS) and compost manufactured topsoil (CMT) at first flush and steady-state. Furthermore, there were no performance differences between 1.3 cm and 5 cm compost applications at first flush or steady-state. The results of this project indicate that particle size, soil moisture capabilities, and time at which rainfall is applied affect surface runoff. TxDOT specification of using ECC at 5 cm depth on a max of 3:1 slope should be reconsidered. An ECC application depth of 1.3 cm was effective in reducing first flush runoff and interrill erosion rates

DEDICATION

I dedicate this to my mother, Linda Birt, and my brother, David Birt, who have supported me throughout my academic career.

ACKNOWLEDGEMENTS

I would like to thank my committee, the departmental faculty and staff, colleagues, friends, and family for all their guidance and support throughout my master's program.

Thanks goes out to Dr. Persyn, my co-chair, for his commitment to me and his encouragement to never give up and always put 110% into my work. A great thank you goes to Dr. Smith for her guidance since undergrad and for being a wonderful co-chair. Also, I would like to thank Dr. Mallick for his enthusiasm in statistics and for serving on my committee.

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CHAPTER I

INTRODUCTION

Urbanization has increased within the United States over the last two decades. From 1982 to 1997, the amount of land developed for urban use has increased by 50%. In particular, Texas lost approximately 13,467 km^2 of quality farmland to development over the previous five years, more than any other state in that period (Land: Agriculture and Urban Sprawl, 2004). As a result of urban expansion, construction activities are increasing throughout the state and the impact of these activities on runoff and erosion has become an important issue in Texas. According to the United Stated Environmental Protection Agency (USEPA) increasing construction activities have led to an increase in nonpoint source pollution (USEPA, 1999).

Stormwater management is important to prevent excessive sediment and nutrients from moving off of construction sites into nearby surface water. The Clean Water Act (CWA) of 1972 cited sediment as a significant pollutant in water systems. In 1987, the CWA was revised to require all states to investigate nonpoint sources of sediment and determine strategies to minimize these sources (USEPA, 1987). Currently, the USEPA regulates stormwater from construction activities as part of the National Pollution Discharge Elimination System (NPDES) (USEPA, 1995). Regulations have become more stringent over time with the implementation of the Phase II rules in 2003 lowering the accepted disturbed area from five acres or larger (Phase I) to one acre or larger (Phase II).

This thesis follows the style of *Transactions of the ASABE.*

Urban development will continue to increase in Texas due to growing population and urban sprawl. Despite the desire for urbanization and expansion of the economy, this growth increases the amount of construction, which if not properly managed, can threaten surface water quality. Therefore, several federal and state agencies are promoting best management practices to reduce stormwater pollutants (Kaufman, 2000). One approach currently being utilized and actively researched by state Departments of Transportation nationwide is to replace the topsoil that was removed during construction activities with organic compost. In particular, the Texas Department of Transportation (TxDOT) has approved and promoted the use of compost as a stormwater best management practice (BMP) during highway construction (TxDOT, 2004). Previous studies concluded that applying compost can reduce erosion (Muhktar, 2004; Persyn et al., 2004). However, since compost can vary widely in its source materials and processing, its use as a stormwater BMP needs further evaluation to optimize or validate current specifications.

The objectives of this study were to construct and calibrate an indoor rainfall simulator and to determine the effectiveness of using compost rather than conventional hydroseeding or topsoil to reduce erosion from disturbed soils. Specifically, this study compares runoff rates, interrill erosion rates, and interrill erodibility factors from five compost treatments and two control treatments after 5 minutes of rainfall (first flush) and during the last 30 minutes of rainfall (steady-state).

CHAPTER II

LITERATURE REVIEW

SOIL EROSION

Soil erosion is defined as the detachment and transport of soil particles (Ellison, 1947; Kaufman, 2000). Two common factors causing soil erosion are wind and water. Soil erosion by water is the result of rainfall impacting the soil surface either through raindrop impact (interrill erosion) or deep sheet flow over a sloped surface (rill erosion), eventually causing soil loss (Meyer and Harmon, 1979; Fan and Wu, 2001; Persyn et al., 2004).

INTERRILL EROSION

Interrill erosion is the result of raindrop detachment and raindrop transport. Raindrop detachment is defined as the amount of soil being separated from the surface. The total amount of soil transported and detached is a function of the kinetic energy, the slope surface, rainfall intensity, and the texture of soil (Hirschi and Barfield, 1988; Haan et al., 1994).

Kinetic Energy

Interrill erosion can result from the kinetic energy of the rainfall impact that applies a force on the soil particles which causes detachment from the surface and movement of soil. The steady impact of raindrops on the surface and the flow which induces transport of soil is known as the interrill raindrop transport (Kinnell, 1990). Interrill erosion rates are affected by raindrop velocity and drop size (Moss and Green, 1983; Kinnell, 1990). The velocity reached at rainfall impact is known as terminal velocity. The terminal velocity is dependent on the diameter of the raindrop and the distance it falls (Foote and DuToit, 1969).

Slope Factor

The slope can influence the erosion rate. As the slope gradient increases, the angle at which the raindrops impact the soil decreases, causing a downward detachment of sediment. As the rainfall intensity increases the transport of sediment downwards increases (Quansah, 1981; Sheridan et al., 2003). Amorim et al. (2001), studied the impact of soil slope on soil loss using topsoil under an indoor rainfall simulator at four different rainfall intensities (30, 46, 69, and 88 mm h^{-1}) on two slopes (2% and 8%). The results concluded that as slope increased by 6 %, the mean soil loss increased by a factor of six. The soil slope affects interrill erosion more than it affects interrill detachment (Haan et al., 1994).

In the Water Erosion Prediction Project (WEPP), a model to predict soil loss, the slope factor was used to account for its impact on the interrill erosion rate (Foster, 1982). Liebenow et al. (1990) defined the slope factor (unit-less) as:

$$S_f = 1.05 - 0.85e^{(-4\sin\theta)} \qquad (1)$$

where θ is the slope angle (in degrees).

Rainfall Intensity and Runoff

Rainfall intensity, the amount of precipitation per time, is a measure of the amount of precipitation applied. Wan and El-Swaify (2001) studied the influence of varying slope (4, 9, 18, 27, and 36%) and rainfall intensity (45, 65, 90, 135 mm h^{-1}) on interrill splash (detachment and transport by raindrops) and interrill wash (sediment transport due to flow) on a silty clay soil. The study concluded at high rainfall intensities

(>60 mm h^{-1}) and steep slopes (36%), the interrill wash increased greatly whereas at low rainfall intensities (<45 mm h^{-1}) and at a steep slope (36%), the wash did not significantly increase.

Soil Texture

Soil can be described using the following characteristics; structure, organic matter, color, pH, and texture. The texture is the proportion of clay, silt, and sand in the soil. The texture of the soil can influence its ability to retain moisture and nutrients for plant growth. The texture of the soil can also impact the interrill erosion rates. When rain impacts the surface, soil aggregates may break up and redistribute to create a layer of smaller soil particles on the surface (Duley, 1939; Bissonnais and Arrouays, 1997). This sheet layer may create a surface seal causing an increase of runoff and erosion. Pore size is dependent on soil texture. Clay soils have small pores and hold considerably more water compared to more sandy soils.

INTERRILL EROSION RATE

The amount of soil detached and transported by raindrop splash is known as net interrill erosion (Haan et al., 1994). Meyer and Harmon (1979) defined interrill erosion as dependent on soil detachment rate and rainfall intensity (Eq. 2)

$$D_i = K_i I^2 \qquad (2)$$

where D_i is the interrill erosion rate (kg s^{-1} m^{-2}), K_i is the interrill erosion factor (kg-s m^{-4}), I is the rainfall intensity (m s^{-1}). This interrill erosion equation is for bare soil and excludes any crop or vegetation factors.

Further studies led to modifications of the interrill erosion rate equation to reflect the relationship between steady-state interrill erodibility, rainfall intensity, and slope factor (eq. 3) (Foster, 1982; Liebenow et al., 1990)

$$D_i = K_i I^2 S_f \tag{3}$$

where S_f is the interrill slope adjustment factor (unit-less).

Hydrologic-based mathematical modeling programs were developed to simulate soil erosion. In particular, the Water Erosion Prediction Project (WEPP) modeled water erosion patterns by incorporating soil type, ground cover, management, climate, slope, and soil erodibility factors (Nearing et al., 1989; Haan et al., 1994; Flanagan and Nearing, 1995; Mark et al., 1998; Persyn et al., 2004). In the WEPP model, interrill erosion is defined as:

$$D_i = K_i I q_i R_i C G\left(\frac{R_s}{R_w}\right) \tag{4}$$

where q is the runoff rate (m s^{-1}), R_i is the sediment ratio (dimensionless), C is percent canopy cover, G is percent of ground cover, R_s is the rill spacing and R_w is the rill width (Weltz et al., 1998).

The interrill erosion rate was then modified to best represent a surface with no vegetation, on a hillslope, and with possible high infiltration rates under steady-state assumptions:

$$D_i = K_i I q S_f \tag{5}$$

where S_f is the slope factor (unit less) (Kinnell and Cummings, 1993). Since it is expected that the blanket applied compost treatments will have high infiltration rates

(Persyn et al., 2004), the equation for interrill erosion rate (eq. 5) was used in this research.

INTERRILL ERODIBILITY

Interrill erodibility best describes the variability of soil erodibility among different by treatments. It can be calculated by:

$$K_i = {D_i}/{IqS_f} \tag{6}$$

The interrill soil erodibility factor can vary among type of treatments due to climatic conditions (i.e. precipitation), management practices, and soil characteristics (Nearing et al., 1989; Alberts and Neibling, 1994; Mamo and Bubenzer, 2001). Persyn et al. (2004) indicated the importance of determining the erodibility factor was its value in modeling materials with different site conditions. In other words, this quantified susceptibility of soil particles to erosion indicates how significant theses parameters can be on soil erosion.

NUTRIENT LOAD AND SEDIMENT

High concentrations of nitrogen and phosphorus transported from urban construction can negatively impact water quality. Furthermore, more than 70 percent of urban streams exceeded the phosphorus standard set by the EPA to control excessive plant and algae growth between 1992 and 1996 (USEPA, 1999). Previous studies indicated that traditional urban highway construction produced greater amounts of total suspended solids and nutrient loadings from runoff than a rural highway (Wu et al., 1998). Minimizing nutrient concentrations from highway runoff will also help to decrease stream pollution. Vaze and Chiew (2004) studied the relationship of nutrient load to particle size in urban stormwater. Less than 15% of total phosphorus (TP) and total nitrogen (TN) were attached to the particles size greater than 300 μm. Compost, which typically has larger particle sizes, might have the potential to reduce sediment load and nutrient movement.

EROSION CONTROL

Composting a biological decomposition process, is typically applied one of three ways for erosion control; incorporated with topsoil (as a soil amendment), as a blanket, or as a filter berm (to diffuse flow).

Mukhtar (2004) conducted a study on the effects of using dairy manure compost for controlling erosion and revegetation on steep slopes. He reported that dairy manure compost resulted in less runoff with fewer total solids than a commercial fertilizer applied to topsoil. Mukhtar (2004) recommended manure compost be applied to highway construction for erosion control.

Buchanan et al. (2002) compared erosion rates of three woodchip treatments (large, small, and mixture) to one control of bare clay loam soil on a 55% slope on a embankment in Knox County, Tennessee. Compared to the bare soil treatment, the erosion rate was reduced by 22% for the “small chips”, 78% by the “large chips” and 86% by the “mixed size” chips. Buchanan et al. (2002) concluded that using larger woodchips can reduce erosion and detachment from the soil on steep slopes.

Persyn et al. (2004) studied erosion along Iowa highways using three different compost blankets; biosolids compost, yard waste compost, and bio-industrial compost, applied at 5 cm and 10 cm depths. They found that a mulch blanket compost applied at a 5 cm depth was an effective application to reduce runoff and erosion, with yard waste compost (coarsest material) performing the best of all treatments.

Currently, the Texas Department of Transportation (TxDOT) has approved and promoted the use of compost as a stormwater best management practice (BMP) during highway construction. Recent studies have shown that compost application will reduce erosion (Persyn et al., 2004; Demars et al., 2000; Storey et al.,1996), improve re-vegetation (Richard et al., 2003), and minimize costs for construction companies (TxDOT, 2004). Evaluating the performance and optimizing these design standards will be beneficial to construction managers, planners and engineers in properly adopting compost blankets as a stormwater BMP.

CHAPTER III

METHODS AND MATERIALS

This study was conducted in laboratory on campus of Texas A&M University using an indoor rainfall simulator. The rainfall simulator was calibrated for an optimal uniformity at a target precipitation rate of 100 mm h^{-1}. Seven treatments were individually constructed in 0.093 m^2 aluminum pans angled at a 3:1 side-slope. Runoff was collected for one hour after rainfall was initiated at time intervals to capture first flush and steady state conditions from each treatment. Erosion measurements were taken and total suspended solids, surface runoff, interrill erodibility, and sub-surface drainage were calculated for all seven treatments.

EXPERIMENTAL DESIGN

Experiments were conducted in the Department of Biological and Agricultural Engineering Water Quality Laboratory at Texas A&M University. Aluminum soil pans were built according to specifications from USDA National Soil Erosion Laboratory (Zheng et al., 2004; D. Flanagan, personal communication, 11 August 2004). According to Weltz et al. (1998), to address interrill erosion rates, it is best to use a small experimental plot (≤ 1 m^2). The height, width, and length dimension for each pan was 0.20 m, 0.33 m, and 0.45 m, respectively (Fig 1).

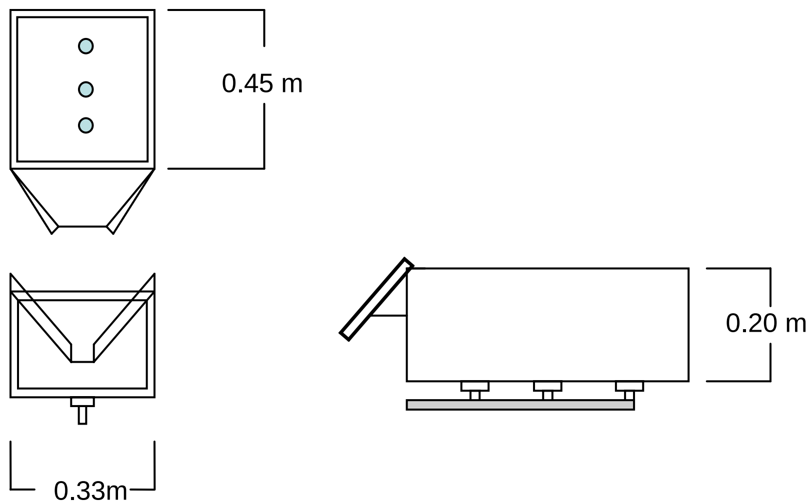

Figure 1. Dimensions of aluminum soil pans modified from Zheng et al. (2004)

Four layers; pea gravel, geo-textile fabric, sandy loam soil, and the treatment media were placed in each aluminum soil pan (Fig. 2).

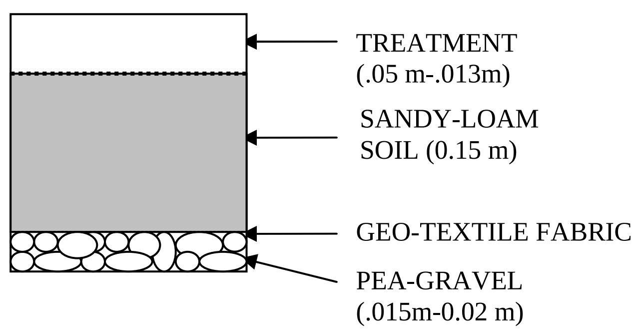

Figure 2. Diagram of the materials used to construct the soil pans

According to Goldman et al. (1986), a 3:1 side-slope is the maximum angle hydroseeding can be applied to be an effective erosion control using the appropriate amount of mulching and tackifier (Fig. 3). Therefore, all soil pans were placed on a 3:1(18.4^{o}) slope.

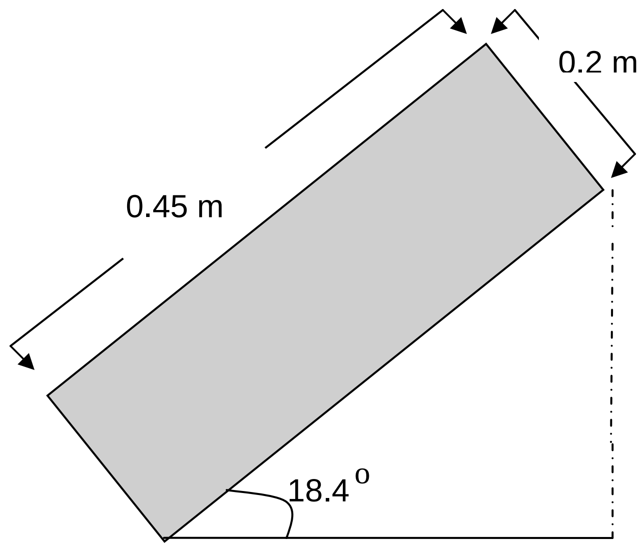

Figure 3. Side-view of the aluminum pans evaluated on a 3:1 side-slope

COMPOST CHARACTERISTICS

The Texas Department of Transportation specifies that compost used for erosion control adhere to both United States Department of Agriculture's "Test Methods for the Examination of Compost and Composting" (TMECC, 2001) and the United States Composting Council (USCC) guidelines. The compost and untreated woodchips were provided by the Brazos Valley Solid Waste Management Authority (BVSWMA) in Bryan, Texas. The compost consisted of fine grain grass clippings and yard trimmings. The untreated woodchips were less than or equal to 12.7 cm in length and had 95% of the sample passing a 5 cm screen and 30% passing a 2.54 cm screen. The compost samples for this experiment adhered to Texas DOT physical standard specifications that require using the Seal of Testing Assurance from the United States Composting Council (Table 1). The BVSWMA used A&L Great Lakes Laboratories, Inc. to verify their compost products adhere to the Texas DOT specifications.

Table 1. Compost physical requirements as specified by Texas DOT following the United States Composting Council Seal of Testing Assurance

	Property	Texas DOT requirement	Test Method
1	Particle Size	95% passing 15.9 mm, 70% passing 9.5 mm	TMECC 02.02-B
2	pH	5.5-8.5	TMECC 04.11-A
3	Soluble Salts	Max 5.0 dS/m	TMECC 04.10-A
4	Organic Matter Content	25-65% (dry mass)	TMECC 05.07-A

TREATMENTS

Seven treatments were tested, five blanket applied compost blends and two controls. A sandy loam soil was obtained through Southwood Valley & Turf, a local landscaping supply company (Fig. 4). The hydroseeding(HS), a blend of grated newspaper pulp, liquid fertilizer (16% Nitrogen, 6% Phosphorus, and 8% Potash), tackifier, Bermuda grass seed, and water (40-60 gal per 1,000 sq ft of dry HS), were provided by Cen Tex Hydroseed, Inc.

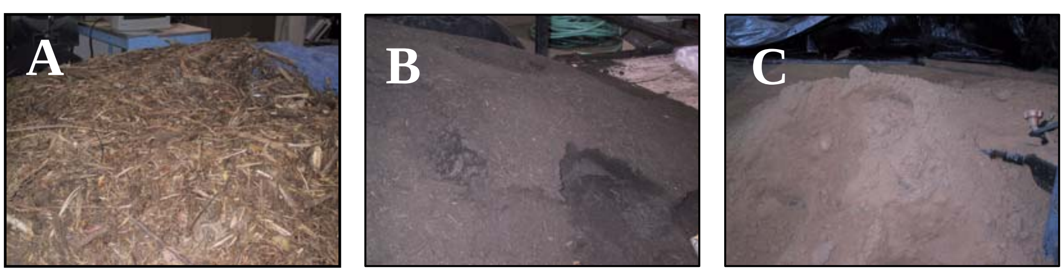

Figure 4. Source materials for treatment
(A: untreated woodchips, B: compost, and C: topsoil)

The samples were sealed and stored at 4 ^{o}C. A physical and chemical analysis of each treatment was conducted by the Texas Cooperative Extension Soil, Water, and Forage Testing Laboratory at Texas A&M University. These results of the multi-nutrient analysis are found in Table 2 and Table 3.

Table 2. Chemical characteristics of treatments

Sample ID	pH	Conductivity [umho/cm]	Nitrate (NO_3) [ppm]	Phosphorus (P) [ppm]	Potassium (K) [ppm]	Calcium (Ca) [ppm]	Magnesium (Mg) [ppm]	Sulfur (S) [ppm]	Sodium (Na) [ppm]
TS	7.8	81	1	3	53	974	116	9	190
CMT	7.9	250	7	190	183	2001	184	43	283
GUC	7.1	718	5	156	848	1733	279	44	326
ECC	6.8	1197	84	813	1032	3376	370	158	518

Table 3. Physical characteristics of samples

Sample ID	Sand [%]	Silt [%]	Clay [%]	Texture
TS	86	4	10	Sandy Loam
CMT	86	6	8	Sandy Loam

For optimal testing results, the compost was stored for no longer than 30 days after mixing the compost (TMECC, 2001).

A concrete mixer was used to blend the materials according to TxDOT specifications for three compost mixtures; compost manufactured treatment (CMT), erosion control compost (ECC), and general use compost (GUC). The CMT and ECC were applied at two depths of 5 cm and 1.3 cm to determine if depth of compost application affects the amount of runoff and erosion. The controls used were a sandy-loam topsoil (TS) and hydroseeding (HS). The GUC and HS were applied at 5 cm (Table 4).

Table 4. Composition and application depths of seven experimental treatments

	Treatment	Characteristic	Application depth
1	Compost Manufactured Topsoil at 5 cm application (CMT-5)	75% topsoil, 25% compost	5 cm
2	Erosion Control Compost at 5 cm application (ECC-5)	50% untreated wood chips, 50% compost blend	5 cm
3	General Use Compost at 5 cm application (GUC-5)	100% Compost	5 cm
4	Erosion Control Compost at 1.3 cm application (ECC-1.3)	50% untreated wood chips, 50% compost blend	<1.3 cm
5	Compost Manufactured Topsoil at 1.3 cm application (CMT-1.3)	75% topsoil, 25% compost	<1.3 cm
6	Hydroseeding (HS)	Paper mulch with fertilizer and Bermuda grass seeds.	5 cm
7	Topsoil (TS)	100% topsoil	N/A

RAINFALL SIMULATOR

A rainfall simulator was used to simulate natural rainfall by distributing rain drops at a specified intensity over an applied period of time. The simulator was designed and operated using the specifications described in Meyer and Harmon (1979) which included nozzle sprayers rather than drop formers. According to previous studies, the flat-spray Veejet nozzles provide a high flow rate with a back and forth movement which allowed for adequate intensities of 3 to 5 mm h^{-1} (Meyer and McCune, 1958; Meyer and Harmon, 1979; Thomas and El-Swaify, 1989; Paige et al., 2003). The rainfall intensity is affected by the kinetic energy and terminal velocity of the raindrops. To insure this study produces raindrops similar to natural rainfall, Veejet nozzles were used (Fig. 5). The flat spray VeeJet 80100 nozzles (Spraying Systems Co.) produce small to medium drop sizes (0.5 mm-3 mm) with an estimated kinetic energy of 75% of natural rainfall having an intensity of 64 mm h^{-1} (Meyer and McCune, 1958; Meyer and Harmon, 1979; Peterson et al., 2002). More specifically, this simulator had a total of ten VeeJet 80100 nozzles at a height of 5 m from the ground and operated at a pressure of 41 kPa.

Figure 5. Rainfall simulator with Veejet 80100 nozzles

The nozzles were controlled by a timing control box and the flow monitors. The electronic box controls the oscillation of the nozzles and the intensity of rainfall (Fig 6).

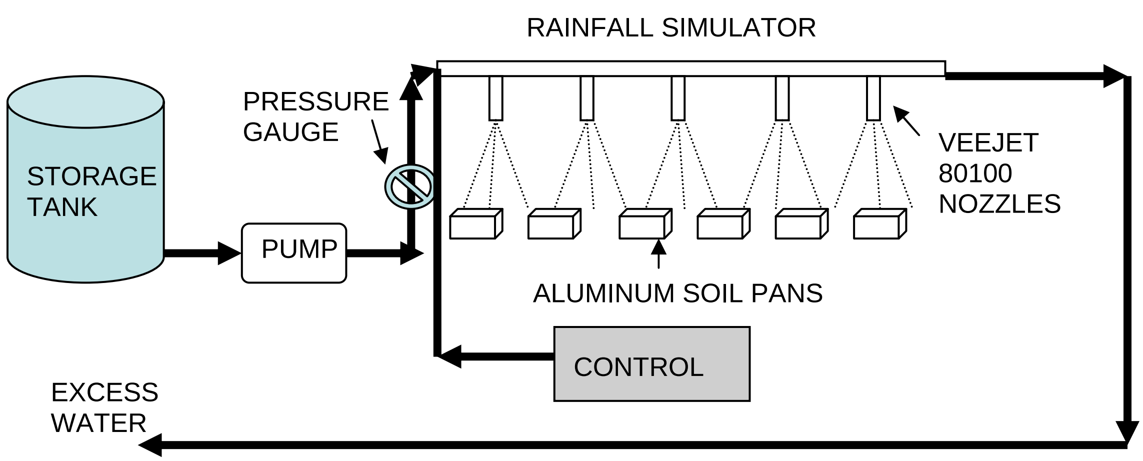

Figure 6. Rainfall simulator

In a previous study, the water source for a field rainfall simulator was deionized water at 40 uS cm $^{-1}$ (Flanagan et al., 2002; Peterson et al., 2002). In this study, potable water pumped from the City of College Station, TX water system was stored in the outside water storage tanks, and then pumped to the rainfall simulator at a flow rate of 41 kPa. (Fig 7).

Figure 7. Water storage tank for rainfall simulator

The U.S. National Weather Service has records of rainfall according to land area (Haan et al., 1994). In the Brazos Valley area, east central part of Texas, a 2 yr, 24 h storm averages between 102 mm h^{-1} to 114 mm h^{-1} in rainfall intensity (Soil Conservation Service, 1986). The target rate for this study was at 100 mm h^{-1}.

Rainfall intensity and uniformity were measured to calibrate the rainfall simulator by collecting the rainfall from an array of catch-cans (Pall et al., 1983; Thomas and El-Swaify, 1989; Edwards et al., 1992; Williams et al., 1998; Humphry et al., 2002; Paige et al., 2003). The intensity and uniformity was tested using 96, 0.95 L aluminum cans which collected rainfall for 30 minutes. The uniformity of rainfall distribution for the rainfall simulator was 89% at an intensity of approximately 100 mm h^{-1}.

DATA COLLECTION

A completely randomized design (Table 5) was used to compare four samples of each of the seven treatments (28 treatment/sample combinations). To reduce the risk of splashing from one treatment to another, a maximum of six pans (treatments) were tested during an individual rainfall simulation.

Table 5. Completely randomized design for layout of treatments

RUNS						
1	2	3	4	5	6	7
ECC-5	TS	ECC-1.3	GUC-5	GUC-5	ECC-1.3	CMT-5
GUC-5	CMT-5	HS	CMT-1.3	CMT-5	CMT-5	CMT-1.3
TS	CMT-1.3	GUC-5	CMT-5	ECC-1.3	HS	ECC-1.3
ECC-1.3	ECC-1.3	ECC-5	ECC-1.3	ECC-5	CMT-1.3	HS
CMT-1.3	GUC-5	CMT-1.3	ECC-5	HS	ECC-5	GUC-5
CMT-5	ECC-5	CMT-5	HS	CMT-1.3	GUC-5	ECC-5

**Acronyms: GUC-5: General Use Compost (5 cm), ECC-5 : Erosion Control Compost (5 cm), CMT-5:Compost Manufactured Treatment, ECC-1.3: Dispersion Treatment ECC, CMT-1.3: Dispersion Control GUC, HS-Hydro-seeding, TS-topsoil

Before each run, the aluminum soil pans were prepared with four layers; pea-gravel, geo-textile fabric, topsoil, and one of the seven treatments. The rainfall simulator mean application rate was 92 mm h^{-1} for 60 minutes. Five plastic rain gauges collected the rainfall for the entire simulation to determine rainfall intensity. Surface runoff was collected in pre-weighed 1L plastic bottles. The first sample was collected after 5 minutes (first flush collection). Then surface runoff was collected for 25 minutes. After the first 30 minutes, runoff was considered to be in steady-state and samples were taken every 5 minutes for the next 30 minutes. Sub-surface drainage was collected during the entire 60 minute rainfall in 6 L graduated flasks. Samples were weighed and recorded.

Total suspended solids (TSS) were determined for each runoff sample. According to the *Standard Methods for the Examination for Water and Wastewater*, samples were filtered (50mL) using a 90mm fiberglass filter paper and dried at 105 ^{o}C oven (APHA, 2004). TSS were calculated ass:

$$TSS = (A - B*1000)/V \qquad (7)$$

where,

A is aluminum dish plus filter (g)
B is Residue and aluminum dish plus filter (g)
V is Volume of sample (ml)
TSS is total suspended solids

DATA ANALYSIS

Interrill erosion begins when raindrops hit the surface of the soil causing splashing to occur. The impact from the splashing causes removal of soil particles from the surface which is known as detachment. This process of detachment and transport of the soil particles is known as the erosion rate (Eq. 8).

$$D_i = \frac{TSS}{A*t} \qquad (8)$$

where,

D_i is the erosion rate (mg/m^2-s)
TSS is the weight of the total suspended solids (mg)
A is the cross-sectional surface area (m^2)
t is the time of runoff collection (s).

The rainfall intensity was calculated from the averaged depths of the five rain gages in each simulation as:

$$I = \frac{\bar{r}}{t} \quad (9)$$

where,

I is the rainfall intensity (m s^{-1})
$\bar{r}$ is the average rainfall depth from five rain gauges (m)
t is the time of rainfall simulation (s)

The surface runoff rate was calculated from the weight of water collected in each soil pan as:

$$q = \frac{W_{H2O}}{\rho_{H2O} * A * t} \quad (10)$$

where,

q is the runoff rate in (mm h^{-1})
W_{H2O} is the weight of the collected surface water (kg)
ρ_{H2O} is the density of water 4 ^{o}C, 1.00 (kg mm^{-3})
A is the cross-sectional surface area in m^2
t is the time of runoff collection (s).

The interrill erodibility factor, K_i, was calculated as (Eq. 6, referenced from Chapter II):

$$K_i = D_i / IqS_f \quad (6)$$

where

D_i =steady-state interrill erosion rate (kg s^{-1} m^{-2})
K_i =interrill erodibility (kg-s m^{-4})
I=measured rainfall intensity (mm s^{-1})
q=measured runoff rate (m h^{-1})
$S_f = 1.05 - 0.85 \exp(-4 \sin \theta)$

where θ is the slope angle (degrees).

To determine the distribution of rainfall on the profile, the general use form of mass balance was used:

$$Rate\ of\ Accumulation = Rate\ of\ Input - Rate\ of\ Output$$

It was assumed that evaporation and transpiration were negligible since the experiment had no vegetation cover and was over a short time period indoors. The water mass balance describes the water applied from the rainfall simulator, the water accumulated in the soil profile, and the water withdrawn from the profile as sub-surface drainage.

CHAPTER IV

EVALUATION OF AN INDOOR RAINFALL SIMULATOR

INTRODUCTION

Evaluation of stormwater best management practices is becoming increasingly important as stormwater managers seek to comply with federal, state, and local regulations. Currently, the United States Environmental Protection Agency (US EPA) regulates stormwater from construction activities as part of the National Pollution Discharge Elimination System (NPDES) (USEPA, 1995). Regulations have become more stringent over time with the implementation of the Phase II rules in 2003 lowering the regulated disturbed area from five acres or larger (Phase I) to one acre or larger (Phase II).

Rainfall simulation has been used in a number of studies to compare best management practices in agricultural and disturbed lands (Bubenzer and Meyer, 1965; Hall, 1970; Meyer and Harmon; 1979; Thomas and El Swaify, 1989; Persyn et al., 2004). Two types of rainfall simulators are typically used: drop formed and nozzle sprayed simulators. Drop formed simulators used hypodermic needles or capillary tubes to produce uniform drop sizes and a screen is used to redistribute the drops (Ekern and Muckenhirn, 1947; Hall, 1970; Bryan and De Ploey, 1983). A drop formed rainfall simulator at a height of 14 m, with a mean drop size diameter of 4.3 mm, using reversed osmosis treated water, with 5 cm tubing lengths, and a stainless drop redistribution screen was constructed to produce droplets similar to natural rainfall (Regmi and Thompson, 2000). According to Regmi and Thompson (2000), the challenges to using a drop former are: (1) “limitations on flow performance due to the frictional and capillary forces”, (2) "difficulties maintaining uniformity at low intensities (such as 1.25 cm h^{-1})", and (3) "restrictions on screen suspension distance affects drop size distribution". In addition, drop formers require as much as 10 m in height for the raindrops to act as natural rainfall when they reach terminal velocity (Grierson and Oades, 1977).

Nozzle sprayed simulators use pressurized nozzles to apply drops at a more uniform rate. Typically these simulators oscillate nozzles to control intensity (Meyer and Harmon, 1979). The advantages to using a nozzle sprayed simulator are: (1) allows for wider variety of intensities compared to drop formed simulators, (2) drop size distribution is similar to natural rainfall at 41 kPa, and (3) uniformity is more consistent when using the oscillated nozzle sprays (Meyer and Harmon, 1979; Edwards et al., 1992).

To facilitate a controlled environment for stormwater best management practice (BMP) evaluation, an indoor rainfall simulator was constructed at Texas A&M University. The simulator was designed and operated using specifications described by Meyer and Harmon (1979) which included using VeeJet 80100 nozzles at a height of 5 m operating at a pressure of 41 kPa.

In previous studies a simple container array method has been used to measure rainfall distributions (Pall et al.; 1983; Thomas and El-Swaify; 1989; Edwards et al.; 1992; Williams et al.; 1998; Humphry et al. 2002; Paige et al., 2003). In those methods, containers were distributed evenly across the range to be tested over a single axis or an area. The nozzles ran for a set length of time, often 30 minutes, at a known discharge rate, and then the containers were measured for the volume of water collected. For nozzle type simulators, the spray pattern of each nozzle varies, so it is recommended that the distribution of each nozzle be determined so that overlap can be designed to increase uniformity (Meyer and Harmon, 1979; Paige et al., 2003). Uniformity coefficients ranging from 76 (Williams et al., 1998) to 94.3 (Thomas and El Swaify, 1989) and 93 (Humphry et al., 2002) have been reported.

The objective of this study was to construct and evaluate the uniformity of rainfall application of an indoor rainfall simulator.

METHODS AND MATERIALS

Rainfall Simulator Characteristics

The simulator was designed and operated using specifications described by Meyer and Harmon (1979) which included using VeeJet 80100 nozzles (Spraying Systems Co.) at a height of 5 m operating at a pressure of 41 kPa. The flat spray nozzles produce small to medium drops sizes (0.5 mm to 3 mm) with an estimated kinetic energy of 75% of natural rainfall having intensity of 64 mm h^{-1} (Meyer and McCune, 1958; Meyer and Harmon, 1979; Peterson et al., 2002). The rainfall simulator was designed to disperse water from two side-by-side laterals (five nozzles per lateral) (refer to Figure 5). Rainfall intensity was controlled by varying the sweep of the nozzles.

Uniformity Standard

Testing uniformity of water distribution is determined by computing the uniformity coefficient (eq. 11) (ASAE S436.1 DEC01 Standards). When computing the coefficient of uniformity, v_i and $\bar{v}$ were replaced with the weight of water collected from each collector and the arithmetic average weight of water per trial.

$$CU_c = 100\left[1 - \frac{\sum_{i=1}^{n} v_i - \bar{v}}{\sum_{j=1}^{n} v_i}\right] \tag{11}$$

CU_c=Christiansen Uniformity Coefficient
n = the number of collectors used in data analysis
v_i = the volume (or alternatively the mass or depth of water collected in the i^{th} collector
$\bar{v}$ = the arithmetic average volume (or average weight) caught by all collectors.

Experiment Setup

The rainfall simulator was constructed in the Department of Biological and Agricultural Engineering's Water Quality Laboratory at Texas A&M University. A total of 96 aluminum cans each weighing 0.09 kg and having a 10.16 cm diameter were used. The cans were evenly spaced (0.3 m) in a grid of six columns with 16 rows. The cans were then placed on a temporary table platform of 5.18 m by 3.05 m, located directly under the rainfall simulator (Fig. 8).

Figure 8. Uniformity distribution testing with 96 aluminum cans

The experimental setup is illustrated in Table 6. Rainfall was applied at a target intensity of 100 mm h^{-1} for 30 min. The 96 cans and collected water were then weighed. This process was repeated three times.

Table 6. Summary of experimental setup

	Rainwater Weight					
	Column					
Row	1	2	3	4	5	6
16	$Y_{16,1}$	$Y_{16,2}$	$Y_{16,3}$	$Y_{16,4}$	$Y_{16,5}$	$Y_{16,6}$
15	$Y_{15,1}$	$Y_{15,2}$	$Y_{15,3}$	$Y_{15,4}$	$Y_{15,5}$	$Y_{15,6}$
14	$Y_{14,1}$	$Y_{14,2}$	$Y_{14,3}$	$Y_{14,4}$	$Y_{14,5}$	$Y_{14,6}$
…	…	…	…	…	…	…
1	$Y_{1,1}$	$Y_{1,2}$	$Y_{1,3}$	$Y_{1,4}$	$Y_{1,5}$	$Y_{1,6}$
Mean	$\bar{y}_{.1}$	$\bar{y}_{.2}$	$\bar{y}_{.3}$	$\bar{y}_{.4}$	$\bar{y}_{.5}$	$\bar{y}_{.6}$

Statistical Analysis

To determine the variability of water distribution from the rainfall simulator, the difference in mean weight of rainfall in each column and row was computed. First, each trial was tested for normal distribution using Q-Q plots. Then an analysis was performed to determine if the rainfall depths were independently and identically distributed (IID) random variables. To test the difference in means for each of the six columns, the one-way Univariate Analysis of Variance (ANOVA) test was conducted (SPSS, 2003). Tukey's procedure was used to conduct a pair wise comparison of the means for each column and row (Ott and Longnecker, 2002).

RESULTS AND DISCUSSION

Column Comparisons

Pairwise comparisons of mean weights showed that the weight of water collected in columns one and six were not significantly different from one another, but were significantly different from the other four columns (Table 7). The inner most columns (2, 3, and 4) were not significantly different from each other. Samples along column five were statistically higher than all other columns. Water drops were observed falling from the simulator along column five that accounts for the significantly higher collection depth.

The uniformity distribution is often calculated to indicate how equal (or unequal) and application rate is throughout a specific area. The uniformity distribution for each column was evaluated in Table 7. Then, the outer columns (1 and 6) and outer rows (1 and 16) were omitted to determine the uniform coefficients for a smaller area, referred to as “edge-effect”. The mean uniformity from all three trials was 89% compared to the 91% when removing the “edge-effect”.

Row Comparisons

Following mean column rainwater weights and column uniformities, the pairwise comparison was again applied to compare the mean rainwater weights among the 16 rows. No significant pattern occurred among the mean row weights indicating the difference in rows was randomy distributed. Table 7 illustrates the highest mean weight was row 7 and the lowest mean was row 16.

The results for the uniformity distribution for each row were more significant after removing the “edge-effect”. The difference in mean uniform coefficients (CU) for the rows before and after the edge-effect removal was 89% to 92% respectively (Table 7). The vertical location of the nozzles (over columns 1&2 and 5&6) appeared to have a substantial impact on the “edge-effect” uniformity coefficients for the rows.

No difference in uniformity coefficients between the total rows and columns suggests that the entire area under the simulator is adequate for experiments.

Table 7. Mean rainwater weight comparison and uniformity coefficients (CU) by row and by column

ROW #	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	AVG	CU (%)	CU - "edge-effect" (%)
	Rainwater Weight [g] (Average of three trials)								
16	0.75	0.99	0.85	0.91	1.06	0.85	0.90[a]	83	
15	0.81	1.02	0.89	0.97	1.13	0.89	0.95[a,b]	87	87
14	0.97	1.21	1.08	1.17	1.38	1.04	1.14[c,d,e]	89	91
13	0.93	0.99	1.12	1.15	1.30	0.94	1.07[b,c,d,e]	89	93
12	0.85	0.90	1.02	0.99	1.17	0.85	0.96[a,b]	86	88
11	0.93	0.95	1.09	1.07	1.25	0.92	1.03[a,b,c,d]	91	91
10	0.99	1.10	1.15	1.18	1.36	1.05	1.14[c,d,e]	90	93
9	0.94	1.13	1.08	1.06	1.12	0.93	1.04[b,c,d]	93	96
8	0.95	1.15	1.08	1.05	1.11	0.85	1.03[a,b,c,d]	92	96
7	1.05	1.34	1.25	1.19	1.27	1.01	1.19[e]	87	89
6	1.09	1.29	1.21	1.16	1.19	1.01	1.16[d,e]	88	93
5	0.91	1.12	0.97	0.99	1.03	0.87	0.98[a,b]	91	91
4	0.93	1.13	1.03	1.03	1.11	0.89	1.02[a,b,c,d]	92	95
3	0.95	1.17	1.13	1.14	1.40	0.95	1.12[c,d,e]	87	93
2	0.83	1.11	0.99	1.07	1.21	0.87	1.02[a,b,c]	89	94
1	0.80	1.11	0.92	1.01	1.15	0.84	0.97[a,b]	86	
AVG*	0.92[f]	1.11[g]	1.05[g]	1.07[g]	1.20[h]	0.92[f]		**89**	**92**
	Coefficient of Uniformity (CU)							Overall CU (%)	
CU (%)	**85**	**90**	**91**	**93**	**86**	**86**		**89**	
CU-"edge-effect" (%)		**90**	**92**	**93**	**85**			**90**	

CONCLUSION

Overall uniformity of rainfall application was good at 89%. Omitting the outer columns and rows (edge-effect) did not improve uniformity. The comparison of mean rainfall weights of each column showed the fifth column was significantly different than all other columns, appeared to be due to an observed water leak from an above pipe. The effective area that can be used with this indoor rainfall simulator was 15.8 m^2.

CHAPTER V

EVALUATION OF COMPOST SPECIFICATIONS FOR STORMWATER MANAGEMENT

INTRODUCTION

Urbanization has increased within the United States over the last two decades. From 1982 to 1997, the amount of land developed for urban use has increased by 50%. Specifically, Texas lost approximately 13,467 km^2 of quality farmland to development, a 42 % increase in rate of loss over the previous five years, more than any other state in that period (Land: Agriculture and Urban Sprawl, 2004). As a result of urban expansion, construction activities are increasing and the effect of these activities on runoff and erosion has become an important issue in Texas. According to the United Stated Environmental Protection Agency (USEPA) increasing construction activities have led to an increase in nonpoint source pollution (USEPA, 1999), and the USEPA (1995) has addressed this concern through regulation of stormwater activities as a part of the National Pollutant Discharge Elimination System (NPDES).

Conventional methods to reduce soil erosion include establishing vegetation using methods such as hydroseeding, wood fiber mats, and straw mats (Faucette et al., 2004). However, there can be limitations to some of these applications. Faucette et al. (2004) reported that hydroseeding can be ineffective for erosion control when applied on slopes greater than 40%. More recently, compost as a soil amendment, erosion control blanket, or filter berm has been used as an alternative best management practice (BMP) to improve soil structure, reduce erosion, or both.

Recent studies have shown that compost application will reduce erosion (Persyn et al., 2004; Demars et al., 2000; Storey et al.,1996), provide adequate re-vegetation (Richard et al., 2003), and minimize costs for construction companies (TxDOT, 2004). Mukhtar (2004) conducted a study on the effects of using dairy manure compost for controlling erosion and revegetation on steep slopes. He reported that dairy manure compost (DMC) and the DMC amended with woodchips applied at an agronomic rate resulted in less runoff with fewer total solids than a commercial fertilizer applied to topsoil. He recommended manure compost be applied to highway construction for erosion control.

Persyn et al. (2004) evaluated erosion along Iowa highways using three different composts; biosolids, compost, yard waste compost, and bio-industrial compost, applied as 5 cm and 10 cm blankets on top of the soil. Treatments were applied on a 3:1 sideslope and rainfall was applied to an average intensity of 100 mm h^{-1}. They reported compost applied at a 5 cm depth was an effective application to reduce interrill runoff and erosion compared to the existing subsoil and a topsoil reapplication method. In addition, yard waste compost, the coarsest raw material used, outperformed all treatments (soil and compost) with the least amount of interrill erosion.

Faucette et al. (2005) evaluated four compost blends, hydroseed, silt fence, and bare soil applied to a 10% sloped sandy clay loam soil at a rainfall application rate of 77.5 mm h^{-1}. The study analyzed runoff volume from seven treatment applications for three storm events; first day of rainfall, three months later, and at twelve months later. At the three and 12 month events, the compost had less runoff volume (mm) than hydroseed 33% vs. 8% respectively. But, in the first storm event mulch, biosolids, hydroseed, and silt fence had no significant difference in runoff volume. More specifically, the municipal solids waste compost infiltrated 51% more water and 24% for hydroseeding compared to bare soil. Faucette et al. (2005) concluded that the time from initial runoff from compost was significantly longer than from bare soil, and attributed this to the high water capacity and diversity of particle sizes in compost. This delay in runoff for compost treatments was also reported by Persyn et al. (2004).

The Texas Department of Transportation (DOT) has promoted the use of compost as a stormwater best management practice during highway construction. TxDOT (2004) specification 1001 also requires that the ECC treatment be applied at a 5 cm depth on a maximum side-slope of 3:1. The American Association of State Highway Transportation Officials (AASHTO, 2003) has a similar compost specification, MP 10-03, which specifies a depth of application of compost between 25 mm up to 100 mm as annual rainfall amounts increase.

The overall objective of this study was to was to compare runoff rates, erosion rates, and interrill erodibility factors from five compost treatments and two control treatments (soil and hydroseed) after the first 5 minutes of rainfall (first flush) and at steady-state.

METHODS AND MATERIALS

Each treatment was individually constructed in 0.093 m^2 aluminum pans angled at a 3:1 side-slope. Rainfall simulation was used to apply a target rate of 100 mm h^{-1}. Runoff was collected for one hour after rainfall was initiated at time intervals to capture first flush and steady state conditions from each treatment. Runoff rate and total suspended solids were measured and used to calculate the interrill erosion rate and soil erodibility factors for each treatment.

Treatments

The Texas Department of Transportation specifies that compost used for erosion control adhere to both United States Department of Agriculture's "Test Methods for the Examination of Compost and Composting" (TMECC, 2001) and the United States Composting Council (USCC) guidelines. The compost and untreated woodchips were provided by the Brazos Valley Solid Waste Management Authority (BVSWMA) in Bryan, Texas. The compost consisted of fine grain grass clippings and yard trimmings. The untreated woodchips were less than or equal to 12.7 cm in length and had 95% of the sample passing a 5 cm screen and 30% passing a 2.54 cm screen. The compost samples for this experiment adhered to Texas DOT physical standard specifications that require using the Seal of Testing Assurance from the United States Composting Council (Table 1). The BVSWMA used A&L Great Lakes Laboratories, Inc. to verify their compost products adhere to the Texas DOT specifications. The sandy loam topsoil was obtained through Southwood Valley & Turf, a local landscaping supply company (Fig. 4, refer to Ch. II). The hydroseeding, a blend of grated newspaper pulp, liquid fertilizers, and Bermuda grass seed, were provided by Cen Tex Hydroseed, Inc.

Three compost mixtures were prepared according to TxDOT specifications; compost manufactured topsoil (CMT), erosion control compost (ECC), and the general use compost (GUC) with composition shown in Table 3 (TxDOT, 2004). ECC and CMT were applied at two depths, 5 cm (ECC-5 and CMT-5) and 1.3 cm (ECC-1.3 and CMT 1.3). The GUC treatment was only applied at the 5cm depth (GUC-5). Hydroseed application was applied at 5 cm to completely cover the surface of the aluminum pan, and represents a larger application when compared to field application. Sandy-loam topsoil was used as an additional control treatment (Table 4, refer to Chapter III).

Experimental Design

A completely randomized design was used to compare four samples of each of the seven treatments (28 treatment/sample combinations) as shown in Table 5 (refer to Chapter III). To reduce the risk of splashing from one treatment to another, six pans (treatments) were tested under rainfall simulator within a 15.8 m^2 area. In addition, each run included one of the two controls (topsoil or hydroseeding).

Aluminum soil pans were built according to specifications received from the USDA National Soil Erosion Laboratory (Zheng et al.; 2004; D. Flanagan, personal communication, 11 August 2004). The height, width, and length dimension for each pan was 0.2 m, 0.33 m, and 0.45 m respectively. Each pan was set on a 3:1 side-slope, the maximum angle hydroseeding can be applied to be an effective erosion control using the appropriate amount of mulching and tackifier (Goldman et al., 1986). Three holes were pierced at the bottom of each soil pan and connected by plastic tubing, 2.54 cm in diameter, to collect subsurface drainage. Four layers, consisting of pea gravel, geo-textile fabric, sandy loam soil, and the treatment media were placed in each aluminum soil pan (Fig. 2, referenced in Chapter III).

Rainfall Simulator Calibration

An indoor rainfall simulator was constructed and calibrated to achieve uniformity of rainfall depth under the simulator. The simulator was designed and operated using specifications described by Meyer and Harmon (1979) which included using VeeJet 80100 nozzles at a height of 5 m operating at a pressure of 41 kPa. Rainfall was applied at a target rate of 100 mm hr $^{-1}$during uniformity testing. Rainfall depth in the cans was measured over a 30 minutes cycle for three replicates. Rainfall uniformity of rainfall was analyzed over a 15.8 m^2 area using 96, 0.95-L, aluminum cans evenly spaced under the simulator in a grid of six columns and 16 rows (Figure 8, referenced to Chapter IV).

Data Collection

Data collection procedures were adapted from those outlined in Persyn et al. (2004) and Mukhtar (2004). The rainfall intensity was controlled by the calibrated rainfall simulator. Five rain gauges were placed under the rainfall simulator; one at each of the four corners and the fifth rain gauge directly in the center of the rainfall simulator distribution area. Each gauge collected rainfall for the entire 60 minutes of application.

Runoff was collected in pre-weighed 1-L bottles 5 minutes after rainfall began (first flush), 30 minutes after rainfall began, at 5 minutes intervals for the last 30 minutes of rainfall (steady-state). Simultaneously, a collection of the subsurface drainage (water infiltrating through this soil/treatment matrix), was taken from the bottom front of each aluminum pan over the entire 60 minutes of rainfall. Samples were stored at 4^{o} C until further analysis could be done.

Data Analysis

The runoff samples collected from each soil pan were used to determine the total suspended solids (TSS) loss and using the Standard Methods (APHA, 2004).

The interrill erodibility factor, K_i, was calculated as (Eq. 6, referenced from Chapter II):

$$K_i = {D_i}/{IqS_f} \qquad (6)$$

where

D_i is steady-state interrill erosion rate (kg s^{-1} m^{-2})
K_i is interrill erodibility (kg-s m^{-4})
I is measured rainfall intensity (mm s^{-1})
q is measured runoff rate (m h^{-1})
$S_f = 1.05 - 0.85\exp(-4\sin\theta), \theta$ is the slope angle in degrees (unit-less)

Equation 6 is best used for steady-state interrill erodibility from mulch blanket applied compost (Persyn et al., 2004). Interrill erodibility factors are used to predict soil erosion in the Water Erosion Prediction Project.

Statistical Analysis

First flush runoff and subsurface drainage data were log-transformed to satisfy assumption that the data were normally distributed and independently and identically distributed. SPSS (2003) software was used to perform an analysis of variance (ANOVA) on the runoff and erosion rate data. Fisher's Least Significant Difference (LSD) was used to do a pairwise comparison of treatment means and handle unequal sample sizes. All tests were done at the $p<0.05$ significance level.

RESULTS AND ANALYSIS

Calibration of Rainfall Simulator

The rainfall simulator had a good uniformity of 89% over 15.8 m^2. The overall comparison of mean rainfall collected was significantly different among the six columns ($P<0.05$) at an application rate of 100 mm h^{-1}. Omitting the outer columns and rows to eliminate any edge-effect resulted in no significant improvement in uniformity (91% vs. 89%).

First Flush

Pairwise comparisons of the first flush runoff rate showed the GUC-5 treatment, with a runoff rate of 30 mm h^{-1} , was significantly different from all other treatments with runoff rates less than 5.0 mm h^{-1} (Table 8). Compost applications having a higher runoff rate were also described by Risse and Faucette (2003), where poultry litter was found to have the highest runoff volume compared to mulch cover because the litter was resistant to water infiltrating into the layers causing the particles to runoff easily from the surface instead of being absorbed by water. Composts can have hydrophobic properties and a material with substantial hydrophobic conditions can lead to a decrease in infiltration (Kladivko and Nelson, 1979; Meyer et al., 2001).

The erosion rates from the first five minutes of runoff showed more significant differences between treatments than the first flush runoff. Erosion rates from highest to lowest followed a trend of finer to coarser particle size distributions in the treatments. CMT-1.3, CMT-5, and TS all containing topsoil and having the finest particles overall had statistically similar mean erosion rates. The erosion rates for the coarser treatments, HS, ECC-5, and ECC-1.3, were not statistically different from one another, but were significantly lower than CMT-1.3, CMT-5., and TS. GUC-5 had the highest mean erosion rate, 8.05 mg m^{-2} s^{-1} and was significantly different from all other treatments.

Table 8. Comparison of mean values of first-flush runoff and erosion rates for seven treatments at rainfall rate of 92 mm h^{-1}

		Runoff rate (mm h^{-1})		Erosion rate (mg m^{-2} s^{-1})	
Treatment	N	Mean	Std. Deviation	Mean	Std. Deviation
CMT-1.3	7	2.42^{a}	1.44	1.49^{d}	1.53
CMT-5	7	2.04^{a}	0.84	1.84^{d}	1.88
TS	2	4.92^{a}	4.96	3.26^{d,e}	2.69
HS	4	2.27^{a}	0.64	0.21^{c}	0.26
ECC-5	7	2.92^{a}	1.66	0.37^{c}	0.23
ECC-1.3	7	2.59^{a}	0.87	0.21^{c}	0.25
GUC-5	7	30.21^{b}	26.4	8.05^{e}	8.01

The coarser mulch blend may aid in runoff reduction due to the decrease in shear forces applied on the soil surface (Adams, 1996; Risse and Faucette, 2003). Therefore, more diverse particle size distribution of compost may lead to a decrease in interrill erosion rate. The depth of compost application (1.3 cm vs. 5 cm) was not a significant factor for either runoff rate or interrill erosion rate for the CMT and ECC treatments.

Steady State

CMT-1.3, CMT-5, and TS had significantly higher steady-state runoff rates and HS had a significantly lower steady-state runoff rates than all other treatments. Faucette et al. (2005) reported that blanket applied compost had significantly less runoff volume compared to hydroseeding; however the application depth of hydroseeding in the Faucette study was much greater than the compost. Steady-state interrill erosion rates followed the same trends as the runoff rates, with the exception that ECC-5 and HS were not significantly different from each other. In summary, HS, ECC-1.3, ECC-5, and GUC-5 had lower steady-state runoff and interrill erosion rates compared toCMT-1.3, CMT-5, and TS.

Table 9. Geometric mean of steady-state runoff rate, interrill erosion rate, and interrill erodibility factors for seven treatments applied at a rainfall rate of 92 mm h^{-1}

		Runoff rate ($mm\ h^{-1}$)		Interrill erosion rate ($mg\ m^{-2}\ s^{-1}$)		Interrill erodibility ($kg\ s\ m^{-4}$)	
Treatment	N	Geometric Mean	Std. Deviation	Geometric Mean	Std. Deviation	Geometric Mean	Std. Deviation
CMT-1.3	7	60.83[c]	17.24	39.72[f]	35.21	11,000[i]	64,000
CMT-5	7	65.79[c]	15.91	44.78[f]	20.40	11,000[i]	31,000
TS	2	58.22[c]	14.46	73.70[f]	29.48	23,000[i]	22,000
HS	4	0.98[a]	0.97	0.01[d]	0.01	510[g]	540
ECC-5	7	5.19[b]	2.70	0.03[d,e]	0.02	910[g,h]	720
ECC-1.3	7	16.70[b]	14.32	0.49[e]	0.74	3,700[h]	4,000
GUC-5	7	17.75[b]	14.56	0.27[e]	0.43	1,600[g,h]	1,800

Interrill erodibility factors were calculated from measured data (Table 9). The erodibility factors for ECC-5, ECC-1.3, and GUC-5 were significantly lower than the CMT-1.3, CMT-5, and TS. Previous study concluded that larger woodchips have significantly more resistance to detachment from raindrop impacts due to the greater chip size which requires a larger amount of inertia to have erosion (Buchanan et al., 2002). Since the TS treatment had the maximum steady-state interrill erosion rate of 73.70 mm h^{-1}, it also had the highest steady-state interrill erodibility factor at steady-state at 0.23 kg-s m^{-4}. Similarly, Persyn et al. (2004) concluded that three compost treatments; yard-waste, biosolids, and bio-industrial (sludge), had a lower interrill erodibility factor than topsoil. Higher erodibility in topsoil compared to the blanket applied composts may be the result of the particle size distribution of the compost.

Distribution of Water Applied to the Profile

The transport of water is related to the treatment type. The mass of water from surface runoff, storage within the treatment layers, and sub-surface drainage was calculated for each treatment. The surface and storage volume for CMT-1.3, CMT-5, and

TS were similar and higher than their subsurface volume. HS, ECC-5, and ECC-1.3 treatments had a greater mass of sub-surface drainage (97%, 96%, and 94 % respectively) compared to the topsoil treatment (Fig. 9). The amount of water that moved through the profile was higher on the HS, ECC-1.3, ECC-5, and GUC-5 treatments, despite equivalent amounts of sandy loam soil beneath the treatment application. It is expected that the covers on these treatments prevented surface sealing and maintained a higher infiltration rate into the profile.

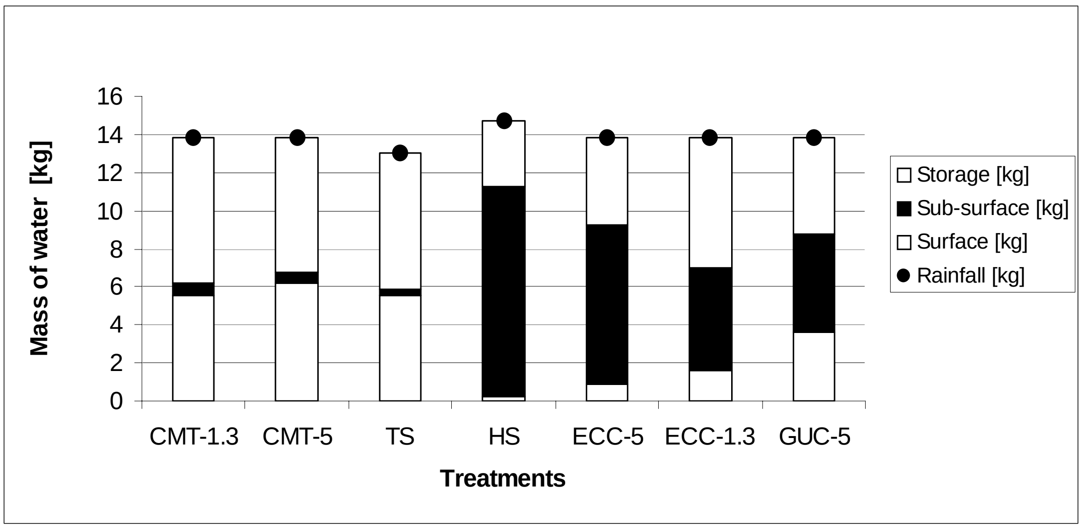

Figure 9. Treatment comparison of surface runoff, subsurface drainage, and soil storage mass (kg) at a mean rainfall rate of 92 mm h^{-1}

Runoff Response

The surface runoff was compared for the seven treatments at both first-flush and state-state conditions (Fig. 10). GUC-5 treatment had a high initial runoff rate (first flush), but runoff dropped after 30 minutes to a steady runoff between 16-20 mm h^{-1}. Previous studies concluded that runoff and erosion rates are influenced by compost characteristics, application rates, and the time between rainfall application and the first runoff (Giddeons and Barnett, 1980; Gilley and Eghball, 1998). This difference in runoff response for GUC-5 compared to soil erosion mechanics might negatively influence the runoff response for compost materials, and require specifications to consider at least some amount of coarse materials.

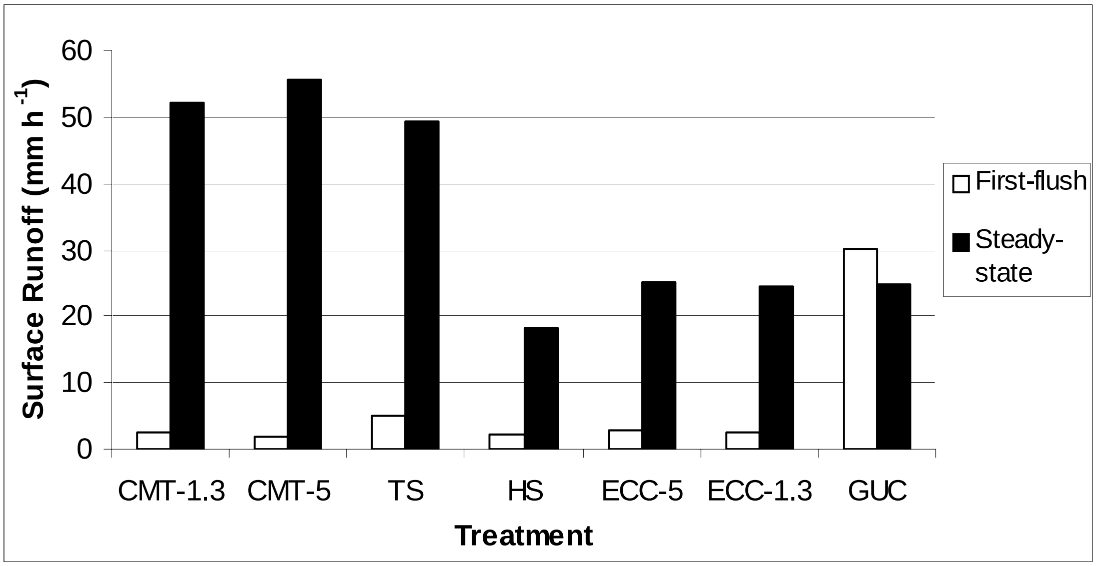

Figure 10. Treatment comparison of surface runoff at a mean rainfall rate of 92 mm h^{-1}

CONCLUSION

The depth of compost application in this study had no significant effect in reducing interrill runoff or erosion, either during first flush or at steady-state conditions; however, the type of compost treatment had a significant impact. General Use Compost (GUC-5) had the highest mean first flush runoff rate and erosion rate in addition to being the smallest particle size compost used in this study. The GUC-5 compost had the smallest compost particle size distribution (and slightly smaller than the Texas DOT specification), but was larger than the topsoil. The GUC-5 runoff response might suggest that small, uniform particle size distributions of compost might exhibit hydrophobic properties until the material reaches particular moisture content.

All other treatments (ECC-13, ECC-5), and hydroseeding (HS) had significantly lower runoff and erosion rates compared to topsoil (TS) and compost manufactured topsoil (CMT) at first flush and steady-state. Although CMT might improve soil structure and accelerate cover crop development, these results suggest that the use of CMT as an erosion control measure is not adequate.

In summary, the ECC compost performance shows that an application depth of 1.3 cm is adequate to achieve runoff and erosion protection superior to topsoil. Interrill erodibility factors were calculated for all treatments at steady state and were comparable to work concluded by Persyn et al. (2004). The response of the GUC-5 compost might suggest that composts with similar performance are not appropriate to model with current erosion prediction tools such as the Water Erosion Prediction Project.

CHAPTER VI

GENERAL CONCLUSIONS

The data provides conclusive results to the comparison of Texas DOT compost specifications and conventional topsoil and hydroseed application for surface runoff, interrill erosion, steady-state interrill erodibility, and sub-surface drainage. The conclusions of this study were:

- GUC-5, a 100% compost treatment, had a significantly higher first flush runoff and erosion rate, than the other treatments due to hydrophobic conditions;
- All the treatments, except GUC-5, had similar first flush runoff rates. Therefore, depth of application was not a significant factor in runoff rates;
- The ECC-5, ECC-1.3, and HS treatments had significantly less first flush erosion rate than the other treatments;
- GUC-5, ECC-5, ECC-1.3, and HS have greater sub-surface drainage than other treatments due to particle size and maximum water hold capacity being reached; and
- No performance differences between 1.3 cm and 5 cm compost applications at first flush or steady-state.

These results suggest that particle size, soil moisture capabilities, and time at which rainfall is applied affect runoff. The TxDOT specification of using ECC at 5 cm depth on a max of 3:1 slope should be reconsidered. An application depth of 1.3 cm is effective in reducing first flush runoff and interrill erosion rates. Yet, source materials of compost and woodchips might have elevated nutrient concentrations that need to be considered when adopting this as a best management practice (BMP).

Statistically similar surface runoff and steady-state erosion indicates that GUC and ECC treatments could be an alternative to current hydroseed application. The minimal materials used for the compost treatments compared to hydroseed may minimize cost while still acting as ground cover to hold moisture, a nutrient enhancer for vegetation growth, and stable enough to sustain wind erosion.

Further use of erosion control treatments of compost and woodchips is suggested to minimize runoff, erosion, and erodibility in lieu of hydroseeding or topsoil application on the hill slopes of highways.

FUTURE WORK

Future research should focus on:

- Evaluating nutrient loads on compost blankets and evaluating the water quality effects;
- Assessing the costs of using compost blankets as a BMP on the hill slopes of highways;
- Analyzing the rill erosion mechanics for blanket applied compost; and
- Investigating steady-state runoff and erosion rates using larger particle sized compost blends

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VITA

Lindsay Nicole Birt
Department of Biological & Agricultural Engineering
Texas A&M University
2117 TAMU, 306A Scoates Hall
College Station, TX 77843-2117
979.845-3692 Office -- 979.845.3932 Fax
lbirt@tamu.edu

EDUCATION

M.S., Biological and Agricultural Engineering, Texas A&M University, May 2007

B.S., Agricultural Engineering, Texas A&M University, May 2004

Texas A&M International Agriculture-Guanajuato, Mexico May 2003/May 2004
International Institute of Women in Engineering-Paris, France, Jul. 2002
Texas A&M Engineering Study Abroad-Paris, France, Jul. - Aug. 2001

PROFESSIONAL EXPERIENCE

May-Aug. 2005 CH2M HILL Houston, TX

Water Quality Intern

- Contributed to the development of a cross-connection/prevention of potable water contamination inspection manual for a major industrial company.

HONORS & AWARDS

National Society of Black Engineers Fellow, 2005
Texas Water Resources Institute Graduate Research Grant, 2005
Graduate Poster Session-TAMU Water Week, Honorable mention, 2005
NSF-Louis Stokes Bridge to Doctorate Fellowship, 2004-2006
Texas A&M University Graduate Diversity Fellowship, 2004

PAPERS & PRESENTATIONS

1. Birt, L.N, Persyn, R.A., Smith, P, 2006. Evaluation of Standards for Compost Blankets in Stormwater Control. American Society of Agricultural and Biological Engineers (ASABE), 2006 Conference. Portland, OR.
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3. Birt, L.N., Persyn, R.A. 2005. Compost as a Stormwater BMP. Southeastern Stormwater Management and Erosion and Sediment Control Conference. Peachtree City, GA.
4. Birt, Lindsay. 2004. Application of FloGrid Fault Property Calculator to a Simple Injector-Producer Pair. ASABE Conference. Ottawa, Canada.
5. Birt, Lindsay. 2004. Application of FloGrid Fault Property Calculator to a Simple Injector-Producer Pair. National Society of Black Engineers. Dallas, TX.